

MULTIVARIABLE OPTIMIZATION FOR ZERO OVER-LIT SHADING DEVICES IN HOT CLIMATE

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ABSTRACT

The climate in Egypt is gifted with a clear sunny sky most of the year, providing the excellent opportunity to benefit from natural lighting yet, there is high risk to exceed the amount of daylighting required for doing a specific task based on the latest standards. Thus, the design for highly efficient and optimized shading device is essential at the first stage.

This research aims to study a South oriented facade and to present optimized solutions for an oval-shaped shading device for a typical office space. The optimization process triggers two main targets, zero over lit floor area with maximum daylit area. Final results also fulfilled the highest daylighting quality based on the values recommended by both IES and LEED V4 standards.

INTRODUCTION

Facade design tends to be one of the challenging tasks for architects in any project. Architects always aim to make a better facade design, which sometimes may contradict with sustainable building requirements, such as the operational energy of the building or providing sufficient daylighting for the interior zones. It is important to take into consideration those aspects during the early phases of the design process. Facade openings are necessary for several reasons; they provide daylighting that may have a considerable positive impact on occupants (Li and Tsang 2008). Many kinds of research had highlighted the importance of windows and daylighting in working spaces with some criteria from a psychological point of view (Boyce et al. 2003; Farely and Veitch, 2001).

Architects are interested in natural light for its vast benefits as well as the opportunities it presents for utilizing various light qualities and color rendering effects (Kim and Chung, 2011). Many studies showed that it is important to exploit daylighting more efficiently to decrease the operational energy of buildings (Kim and Mistrick, 2001; Neida et al. 2001; Knight, 1999). Artificial lighting consumes about 20% up to 30% of the total energy load of non-domestic buildings (Li et al. 2002), therefore daylighting in architectural design has been incorporated dramatically to help in reducing the overall energy consumption of a building (Li and Lam, 2001; Atif and Galasiu, 2003). Yet, it is still a hard task to

moderate illuminance levels in interior spaces when designing the fenestrations of a certain building, as the architect usually needs to tackle many variables such as, window to wall ratio (WWR), glazing types, shading device parameters and its reflectivity factor, not to mention operability schedules for operable shading devices that require more dynamic tool.

DAYLIGHTING AND SIMULATION

In the last few decades, computer simulation has been widely used in studying building energy and environmental performance. Simulation tools are capable of engaging decision making according to whatever evaluated environmental impact, such as daylighting or energy consumption (Caldas and Norford, 2002).

Earlier, Reinhart claimed that one reason for the overoptimistic energy-saving predictions and the ignorance of the designers towards daylighting is due to the lack of informative daylight performance indicators (Reinhart 2002). Later on, climate-based daylight metrics (CBDM) were developed and promoted by building rating systems and standards. Another engine simulation tool named DAYSIM was developed, which is capable of calculating the annual performance of daylighting that represents a step towards the better assessment of daylighting instead of Daylight Factor (DF) metric or point in time illuminance calculations (Reinhart and Walkenhorst 2001). The annual climate based metrics and tools are considered revolutionary in the field of daylighting simulation.

Several studies have documented the increasing use of Daylight simulations (Reinhart and Fitz 2006; Galasiu and Reinhart 2008). Nevertheless, the institutions responsible for setting criteria for sustainable buildings, such as the US Green Building Council (USGBC), consider daylighting simulation according to the latest CBDM metrics. Standard 189.1-2009, which is a result of a joint effort between ANSI/ASHREA/USGBC/IES, requires daylighting simulation for usable spaces in office buildings and classrooms. Lately, institutions changed assessment criteria according to the latest methods provided by daylighting simulation tools. Illuminating Engineering Society of North America (IESNA) is promoting the use of dynamic annual metrics, such as spatial daylight autonomy, while the latest version of

the green buildings rating system LEED v4 includes daylight autonomy metric in assessing daylighting in office and healthcare buildings, which can be found in the Indoor Environmental Quality (EQ) Credit 7 (USGBC, 2013).

Some researches were conducted to find suitable configurations for fenestration designs in hot climates using the latest tools for calculating daylighting and energy consumption. Trials have been made to make a compromise between two conflicting goals, the amount of daylighting and the energy consumed for cooling and lighting loads (Hegazy et al. 2013; Hegazy and Moro 2013). Others focused on the optimization of daylight performance by optimizing the configurations for shading devices according to various conditions (Wagdy & Fathy, 2015; Wagdy, 2013), which resembles an advanced method of simulation and assessment still typical static shading devices have a problem to achieve 100% daylit area with no direct sunlight (0% ASE); therefore, an advanced technique was needed to develop this shading device.

As for hot climate regions with clear sky conditions, direct sunlight has a significant influence on increasing the heat gains when passes through the windows of any room, which requires more energy consumption, especially for cooling. The applied method used in this research is brought from the field of Artificial Intelligence (AI), which is Genetic Algorithms (GAs) and Optimization. It provides the designer with novel ways to generate goal – oriented design solutions based on a specific performance (Turrin et al., 2011; Rakha and Nassar, 2011). However, it is hard to define proper evaluation criteria for the optimization yet, especially when it comes with conflicting requirements, such as daylighting and internal heat gains. From this point, the authors put more strict criteria and use advanced tools and techniques to achieve this goal.

One of the most powerful tools is Rhinoceros / Grasshopper (Shi and Yang 2013) used to study a performance-driven design with Galapagos as a third-party program for the optimization process. Rhinoceros and Grasshopper have been widely used in many of the architectural and urban leading schools especially in the conceptual and development phases of design (Reinhart et al., 2013).

Research Aim

The Authors aim to achieve maximum benefit of daylighting with optimal visual and thermal comfort through strict criteria that comply and surpass IESNA Standard and LEED v4 rating system. This paper presents a state – of – art computer-based technique to generate a shading device for southern façades that fulfill the following criteria:

- 100% Daylight Autonomy
- Zero percent Annual Sunlight Exposure

- Zero percent Over lit
- 100% Daylit area

METHODOLOGY

A review has been conducted in the previous section showing the evolution of using dynamic daylighting metrics throughout the last 15 years. The test was run on a hypothetical model of an office room. Given that available simulation tools are still limited to the metrics they calculate; it was important to develop a new technique to be capable of producing individual and unique requirements for assessing daylighting for indoor spaces.

The assessment in this paper include the latest requirements by rating systems and standards such as LEED v4 and IESNA. A minimum percentage of 75% of room area for Spatial Daylight Autonomy (sDA_{300/50%}) is recommended by IES and is defined as the percentage of floor area, for at least 50% during occupied hours (8am-6pm), in which 300 lux of illuminance is reached throughout the year (IESNA, 2012). A maximum percentage of 3% of room area for Annual Sunlight Exposure (ASE_{1000/250hr}) is preferred as well and is defined as the percentage of floor area, for at least 250 hours during occupied hours (8am-6pm), in which 1000 lux of direct illuminance is reached throughout the year (IESNA, 2012).

Moreover, Daylight Availability metric was used; it divides daylighting into three categories; a partially lit area for low illuminance levels, a daylit area for sufficient amount of daylighting and an overlit area for illuminance levels ten times the targeted illuminance for at least 5% of the occupied hours.

Case Study

A hypothetical model was built up using Grasshopper and Rhinoceros 3D software with dimensions (6m length x 4m width x 3m height) shown in Figure 1. The room is presumed to be located in Cairo, Egypt, Latitude 30.1 and Longitude 31.4.

The simulation was conducted with the weather data file of Cairo that represents a hot climate zone conditions. The model is an office room with occupancy schedule starting from 8:00 till 18:00. For worst case condition, no surroundings have been built so that to consider any possible direct sunlight entering the zone. A simulation was carried out on an analysis grid with 50*50cm spacing, 25cm offset from all sides and 80 cm height above the floor level.

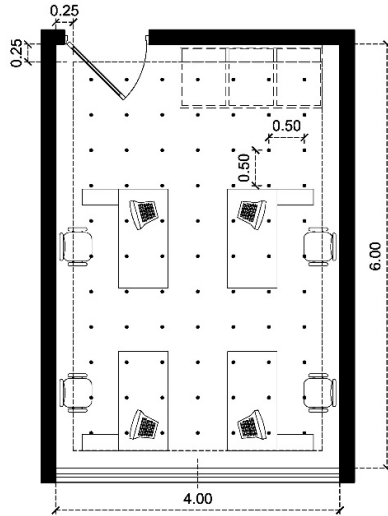


Figure 1 A hypothetical office room with one window facing the south.

Figure 2 shows different window ratios that were parametrically defined, ranging from 5% to 90% using the same parametric method by (Sherif et al., 2014). Only the southern façade window was tested in this research work.

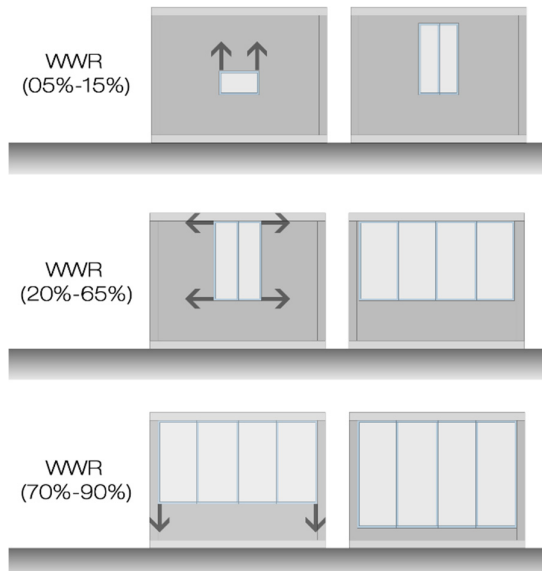


Figure 2 Window configuration and positions according to the different window ratios

Reflectivity ratios of the internal surfaces were defined according to the generic values provided by DIVA-for-Rhino, a daylighting simulation plugin works with Rhinoceros 3D and Grasshopper (Jakubiec and Reinhart, 2011). In Table 1, parameters of the hypothetical room used in the simulation process are defined in details.

The following Tables, 2 and 3, show Radiance parameters used to calculate the Spatial Daylight

Autonomy (sDA), Daylight Availability (DA) and Annual Sunlight Exposure (ASE).

Table 1
Design parameters for the tested room

OFFICE ROOM PARAMETERS			
Floor Level		First Level	
Dimensions		6m x 4m x 3m	
Area		24 m ²	
Reflectivity Ratios	Ceiling	80%	White Paint
	Walls	50%	Medium Off-White Paint
	Floor	20%	Wooden Floor
Window orientation		South	
Occupancy Schedules		08:00 – 18:00	

Table 2
Radiance simulation parameters for Daylight Availability & Daylight Autonomy Metrics

Ambient bounces	Ambient divisions	Ambient sampling	Ambient accuracy	Ambient resolution
6	1000	20	0.1	300

Table 3
Radiance simulation parameters for Annual Sunlight Exposure Metric

Ambient bounces	Ambient divisions	Ambient sampling	Ambient accuracy	Ambient resolution
0	1000	20	0.1	300

Base Case Results:

According to the Base Case configuration and parameters, a simulation was run at 18 different window ratios with no shading. In the following graphs, in Figure 3, simulation results illustrate the daylighting performance of the base case with 18 window size iterations over three different metrics. Two iterations were analyzed based on the defined criteria for maximizing the Spatial Daylight Autonomy (sDA) area, while keeping Annual Sunlight Exposure (ASE) values less than 10% together and reaching zero over lit area.

On one hand, for a minimum window ratio of 5 % it got a small overlit area and ASE of 6% and 88 % of the partially lit area, while Daylight Autonomy reached only 9 %, which is below LEED rating criteria and IESNA standards. On the other hand, a window ratio of 25 % got 100% of Daylight Autonomy and zero partially lit area, but the over-lit area reached 43%, and ASE reached 39%, which exceeds the acceptable range in LEED as shown in in Figure 3 and Table 5. Thermal wise there is a high possibility of getting an extra amount of heat gain that raises the energy consumption consequently.

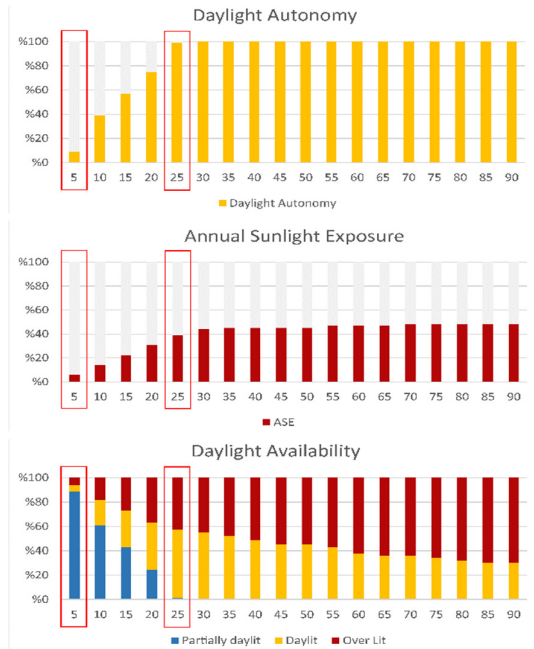
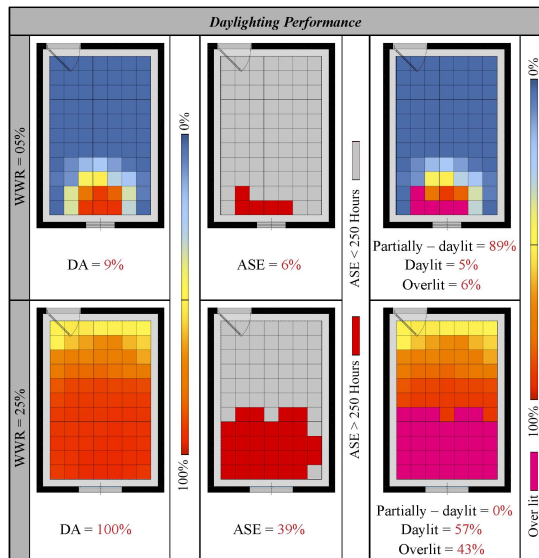


Figure 3 Daylight performance of (sDA, ASE, DA) for 18 windows to wall ratios (5% to 90%)

It is evident that a window without any improvements can barely achieve an adequate amount of daylighting. In most cases, it only achieves whether an extra amount of daylighting or partially lit and dark areas at the end of any defined room. Recommendations for shading devices and their configurations over the different facades are still missing in the Egyptian codes (EERB, 2008). Detailed daylighting distribution is shown in Table 5 for the base case with window ratios 5% and 25%.

Table 5
Daylight performance of (sDA, ASE, DA) for 18 windows to wall ratios (5% to 90%)



Shading Device Design

The aim is to design a shading device that prevents any direct sunlight exposure. The process of creating this shading device involves several stages; first, two-point references were defined at the bottom edges of the window frame; those two points were then used as the center of the sun path compass in grasshopper. Second, the shape was formed by intersecting the semicircles formed by the sun path diagram shape for a particular day, which was associated with the sun motion, specifically sunrise to noon on one side and from noon to sunset on the other hand. Third, a straight line was drawn between the top tangents that formed the outline of the shading device, which looks like half a rectangle with filleted edges. The outline of the shading device is lofted with the window upper and side edges to complete the final form shown in Figure 4. As a basic configuration, it was presumed to prevent any direct sunlight; however, the dimensions were optimized parametrically to achieve best daylighting performance based on the predefined criteria.

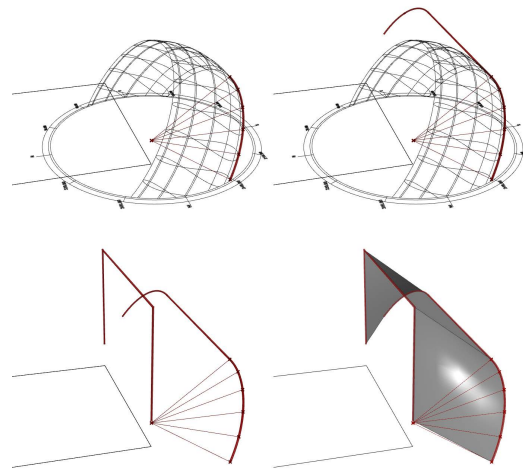


Figure 4 Shading device design steps

Shading Device Variables

Four different variables were parametrically optimized as shown in Table 6; Window Ratio, shading device extrusion, the shape of the sun path diagram on a particular day, and reflectivity percentage of the shading material.

Table 6
Optimization parameters for shading device and window ratio

OPTIMIZATION PARAMETERS	
WWR	05% - 90% (5% step)
Sun Path (Date)	21/01 - 21/12 (1-month step)
Shading Reflectance	35%, 50% and 80%
Shading Extrusion	0.1 – 2.5 meter

RESULTS AND DISCUSSION

Iterations

The optimization process was realized after 585 simulation runs, counting almost 6 consecutive days. As shown in Figure 5, simulation results are ordered from the worst performance cases to the optimized ones. The genetic algorithm enhanced daylighting performance during the optimization process gradually throughout 29 Generations, by which the objective was set to maximize daylit area percentage and to minimize the over-lit and ASE area percentages. In the last generation, by the end of the optimization process, three optimum solutions were defined that met the targeted criteria.

While optimum solutions already comply with the mentioned criteria, the last 96 individual solutions alone can achieve 3 credit points in the LEED.

The performance of the final solutions is very similar regarding daylighting performance even though they are not identical. Shading device configuration varies, by which the extrusion of the shading device is inversely proportional to the reflectivity value of the

shading material as shown in Table 7. A sample of daylighting performance is presented in table 8. The daylit area reached 100% of the room, which left no space for overlit or partially daylit areas. It returns to the very high values of each analysis point that shows more than 50% of the room was always illuminated with 300 lux or more for more than 90% of total occupied hours.

Additionally, daylight availability metric verifies the high quality of daylight for the same area. Although radiance parameters were set with 6 ambient bounces, illuminance levels did not exceed 3000 lux at any of the analysis points. Finally, the Annual Sunlight Exposure (ASE) analysis gave another dimension to the daylighting performance. It shows that a small amount of direct sunlight could enter the space that did not access 250 hours at any point. This metric is an excellent indicator of assessment for excessive internal heat gains that raises the temperature of a zone lies in a hot climate area condition. Sunlight also represents a primary source of possible glare, which is considered to cause visual discomfort, especially for office areas.

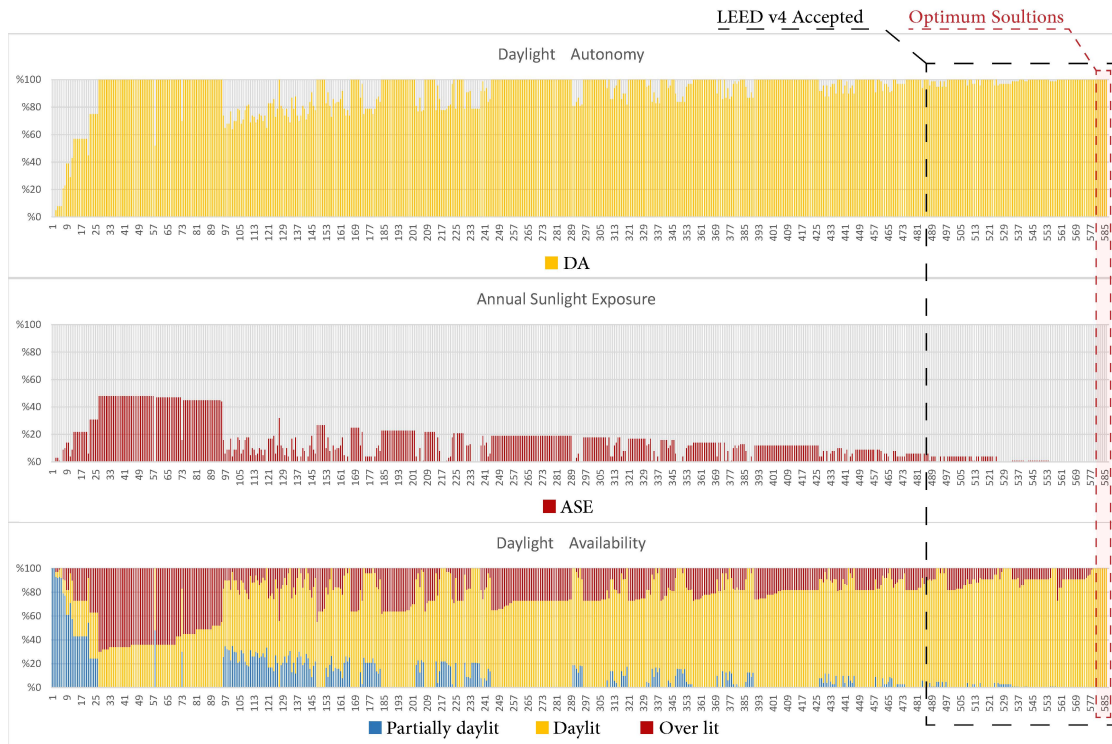


Figure 5 Optimization results for according to DA, ASE and Daylight Availability metrics

Table 7
Shading device configuration for the optimum results

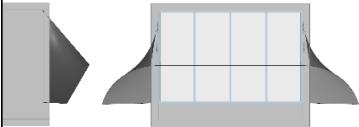
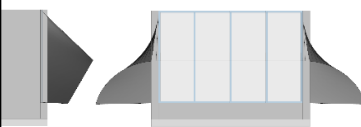
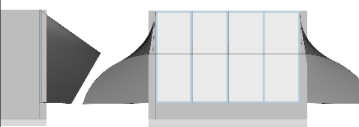
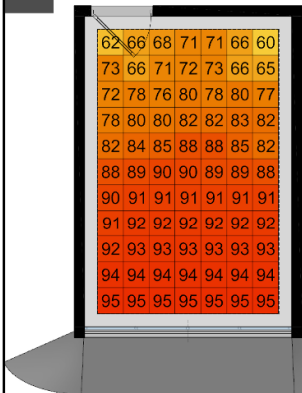
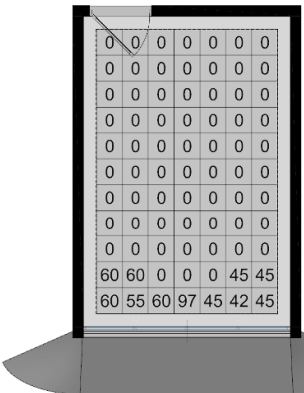
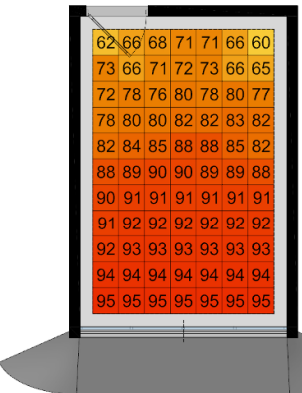



The Optimized Solutions					
A	B	C			
					
Shading Extrusion = 1.7 m Sun path = 21 December	WWR = 85% $\rho = 80\%$	Shading Extrusion = 1.9 m Sun path = 21 December	WWR = 85% $\rho = 50\%$	Shading Extrusion = 2.2 m Sun path = 21 December	WWR = 85% $\rho = 35\%$

Table 8
Daylight performance for optimum results

Daylighting Performance		
A		
		
Daylight Autonomy = 100%	ASE = 0%	Partially – daylit = 0% Daylit = 100% Overlit = 0%
		

CONCLUSION

During the last few years, the field of daylighting has developed dramatically. Many publications and studies work on producing precise and validated metrics for daylighting, which can guide architects and designers during their early and late phases of design. Researchers do not gather on one metric to use it for daylight assessment yet, unless it is defined by an association, such as the Illuminating Engineering Society of North America (IESNA), local codes, or a rating system, such as LEED.

This paperwork applies strict daylight performance criteria that also comply with the latest LEED v.4 requirements and IESNA. The authors developed a unique method using parametric tools and daylighting simulation to bring up the targeted results. For hot climates, sunlight is the primary source of natural light

as well for heat gain and increasing indoor temperature. The priority concept was to develop a shading device that prevents direct sunlight to enter, to guarantee minimum heat gain. Furthermore, to avoid the usage of artificial lighting that again raises the internal heat gain, it was important to provide a good amount of daylit area which has already reached the 100%, in this case.

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